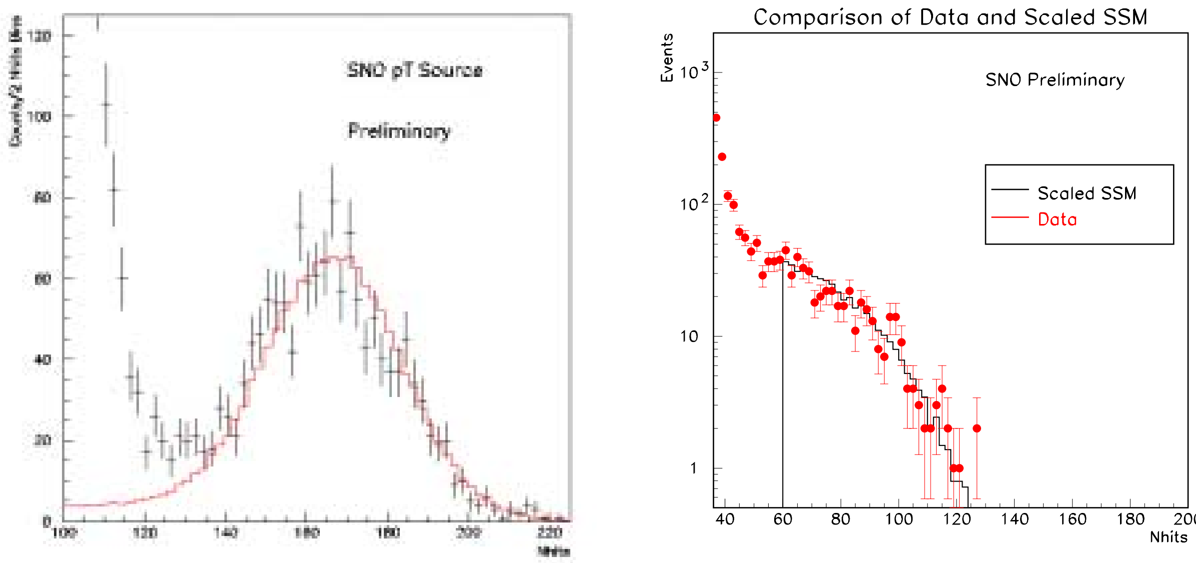

Left figure: SNO's critical High Energy (20 MeV) p-T Calibration Source Data. Right figure: SNO's first report of the charged current spectra.

Institute for Nuclear and Particle Astrophysics Overview

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Introduction

The areas of research at the Institute (INPA) are broad and have a strong interdisciplinary flavor, yet a common purpose connects them - to use the science and the technologies of nuclear physics and particle physics to address fundamental questions bearing on the nature of the universe: past, present, and future. Specific research topics include solar neutrinos, high energy neutrinos, detection of nearby and distant supernovae, weak interactions in atomic and nuclear processes, the cosmic microwave background radiation, direct detection of dark matter, cosmic ray chronometers, the theory of pulsars and neutron stars, and geoastrophysics. Research and education are combined not only through the participation of students and postdoctoral researchers, but also at the high school level through summer programs for teachers and a major project, the Hands-On Universe, that brings on-line astronomical images to the classroom.

INPA is sponsored by the Nuclear Science Division and the Physics Division at LBNL. While participants in INPA are predominantly from these two Divisions, the Physics Department and the Space Sciences Laboratory at UC Berkeley are well represented. Indeed, the Institute benefits from the rich concentration of astrophysics in the greater Bay Area. A wide range of experimental facilities is used by INPA participants; at LBNL (the 88-Inch Cyclotron, Gammasphere, Low-Background Counting Facility, Leuschner Observatory), in North America (Sudbury Neutrino Observatory, the Keck Telescopes, nuclear physics facilities at national laboratories and university laboratories), throughout the world (Chile, Australia, Antarctica), and in space (Hubble Space Telescope). There is increasing interest in the study of neutrino properties and their use as probes of very energetic objects in the universe.

This overview naturally focuses on research where Nuclear Science Division-associated researchers are heavily involved. A few highlights from other areas are mentioned, and the overview concludes with a brief description of INPA's institutional activities.

Neutrinos and Neutrino Astrophysics

The Sudbury Neutrino Observatory (SNO), a 1,000-tonne heavy-water Cherenkov detector located in a nickel mine in Canada, is nearly the completion of its first phase of neutrino detection — the pure D_2O phase. In this phase the SNO detector will extract the charged current flux and spectum, the elastic scattering flux and spectrum and determine principal background signals in the detector. Analysis of the data at LBNL and within the collaboration has kept pace such that SNO's first experimental results are anticipated in late Spring of 2001. The Neutrino Astrophysics group is playing a significant role in data analysis. Analysis activities have included i. the development and refinement of data reduction techniques to eliminate dominant non-physics backgrounds, ii. development of Monte Carlo programs characterizing backgrounds and detector performance, iii. development of event fitters and goodness-of-fit parameters to permit accurate event reconstruction and event classification, iv) estimates of intrinsic backgrounds in the heavy water, acrylic vessel and light water regions of the detector and vi) signal extraction techniques using all these tools. Recently, a high energy gamma-ray source (p+T) has been successfully installed and operated, enabling accurate calibration of SNO s multi-hit and high-energy response over the full solar neutrino signal region. The next phase of operation will begin with the addition of salt to the D_2O to accurately extract the neutral current signal using different systematics than the current measurements in pure D_2O. A result for the charge-current solar neutrino flux, a comparison to elastic scattering, and determination of significant backgrounds are anticipated by Spring, 2001.

The same properties of neutrinos that make them a valuable probe of the sun could also make them a unique window on the most energetic objects in the cosmos. A number of INPA participants are members of the AMANDA collaboration, which has constructed a water Cherenkov detector in deep Antarctic ice to observe high energy neutrinos. With 19 strings of PMTs operating, AMANDA is currently the largest neutrino detector in operation. It has detected up-going muons, the signature of high energy neutrinos and placed upper limits on a number of exotic processes. Several hundred atmospheric neutrinos have been detected so far in an analysis of data take in 1997. INPA, with cooperation from NERSC, is also heavily involved in the analysis of the large amounts of data generated by the current array. The digital technology developed at LBNL and demonstrated with a string of 41 digital optical modules, has become the technology of choice for IceCube, the kilometer-scale neutrino detector proposed as the successor to AMANDA. This future detector should have the sensitivity to detect neutrinos from distant point sources, such as Active Galactic Nuclei or Gamma Ray Bursters. INPA is also making a major contribution in the planning and R&D toward the next generation neutrino observatory.

The properties of neutrinos, in particular, whether they have mass, are of fundamental importance to astrophysics and cosmology, as well as to the standard model of particle physics. SNO is a prime example of a neutrino oscillation experiment. KamLAND, a detector under construction in Japan, is another. The U.S. collaboration for KamLAND has formed and LBNL is now actively involved in a number of important aspects of the design and construction, especially the data acquisition electronics. KamLAND will use 1200 m^3 of high purity liquid scintillator to detect anti neutrinos from nuclear power reactors over 100 km away. This long baseline provides a sensitivity to neutrino oscillations that extends down in Δm^2 to a region also covered by SNO (the "large mixing angle" solution"). First operation of KamLAND is anticipated in late 2001. The question of neutrino mass is also addressed by the double beta decay experiment CURORICINO, which is planned for the Gran Sasso underground laboratory. LBNL is involved through its Materials Science Division by developing the NTD Ge thermistors that detect and measure the energy of the two electrons emitted in the decay of ^{130}Te, and the Low Background Counting Facility, which examines components of the detector for trace amounts of radioactivity.

Nuclear Astrophysics

The scientific goals here are to understand the nuclear reactions, astrophysical sites, and physical conditions required to produce the elemental and isotopic composition of the matter found in the universe; to determine properties of neutrinos, especially as they relate to astrophysics. In collaboration with Dr. Paul Renne of the Berkeley Geochronolgy Center, this group has used mass spectrometry to accurately measure the half-life of ^{37}Ar. A precise value of this half-life is needed to interpret the ^{37}Cl solar neutrino experiment of Ray Davis. They completed analysis of their data taken to determine the endpoint energy of the inner-bremsstrahlung spectrum of ^{179}Ta. This quantity is needed to determine the suitability of ^{17}9Ta electron-capture decay for a future neutrino mass experiment. Work has begun at the Gran Sasso underground laboratory in Italy in preparation for mounting the experiment CUORICINO mentioned above.

Data for Nuclear Astrophysics

Nuclei heavier than lithium can only be made in stars, and in the later, rapid-burning and explosive stages of stellar evolution. The prediction of the abundance of these nuclei is a triumph of nuclear astrophysics, and requires an amount of nuclear information on a similarly grand scale. INPA, the Isotopes Project, and UC Santa Cruz have assembled a number of the data-bases used in nucleosynthesis calculations and made them available to the community through our new Nuclear Astrophysics Data Home Page. The type and range of data available through this site has continued to grow as has the number of visitors to the web site.

Weak Interactions and Fundamental Measurements

The standard model of particle physics is the cornerstone for understanding the origin and development of the universe. Many of the key elements or parameters of the standard model are reflected in nuclear properties and measured in precision low-energy nuclear (or even atomic) experiments. It is possible to establish, test, and look for physics beyond the standard model in these experiments. Parity non-conservation, second class currents, time reversal invariance, the conserved vector current theory, double beta decay - these are some of the topics studied in the physics of weak interactions. Progress continues to be made in a series of experiments on laser trapping, parity non conservation, neutron decay (time reversal invariance and parity violation), ^{14}O and ^{14}C (test of the CVC hypothesis) ^{10}C (unitarity of the CKM matrix), and Yb (atomic parity non-conservation). Some of these experiments are done at the 88-Inch Cyclotron and described elsewhere in this report.

Low Background Counting

The Low Background Counting Facilities used in the study of $\beta\beta$ decay have also been instrumental in a wide variety of experiments and in support activities for other institutions. The other types of work (done at the facilities at Berkeley and at Oroville) include low-activity materials certification, cosmic ray activation, neutron activation analysis, and environmental health and safety activities.

Astrophysics and Cosmology in the Physics Division

We mention here two INPA projects that address the early history and the ultimate fate of the universe and which are based in the Physics Division. The cosmic microwave background radiation observed today reflects the state of the universe about $3x10^5$ years after the Big Bang, at the time radiation and matter decoupled. The next generation of satellites, to follow COBE in the study of anisotropies in the CMBR, is being planned.

The fate of the universe depends on its matter density, which is expressed as a ratio to a critical density at which the expansion rate of the universe slows to zero at infinite time. The supernova cosmology project searches for (and regularly discovers!) type 1A supernovae at very large distances. In essence, the luminosity of a type 1A supernova is a constant or "standard candle," which gives its distance, and the red shift of its host galaxy gives its velocity. Thus, the Hubble diagram can be extended to very large distances (or far back in time). Deviations from a linear dependence of recessional velocity on distance have indicated that Ω_M (the ratio of the mass density of the universe to the critical value) is substantially less than 1 and, equally momentous, that the cosmological constant, Ω_λ, originally proposed by Einstein and later retracted, is finite. The small value of Ω_M and finite Ω_λ imply that the universe will expand forever. A proposal for a space telescope, called SNAP and to be dedicated to the deep search for Supernovae, has been submitted.

Institutional Activities

The purpose of the Institute is to further interdisciplinary work in Nuclear and Particle Astrophysics at LBNL by:

- promoting interaction and communication among its members

- sharing of intellectual, technical, and administrative resources

- planning of new research proposals and development of detector systems
- developing innovative educational outreach programs
- establishing seminar, postdoctoral, and visitor programs
- sponsoring of workshops

The list of active participants has grown to approximately 90, while the number of people receiving e-mail announcements of the weekly Journal Club is ~200. Attendance at the Journal Club is typically 30-40 people. The daily tea has become an established feature of INPA life and attracts usually 15-20 people -students, post-doctoral fellows, and staff - for conversation and lively argument. The Common Room is heavily used for regularly scheduled group meetings and ad-hoc get-togethers.

INPA hosted or co-hosted 6 meetings and/or workshops, and had sixteen visitors.

Additional information on the Institute and its activities can be found on the World Wide Web under the URL http://www-inpa.lbl.gov/.